FIG. 1

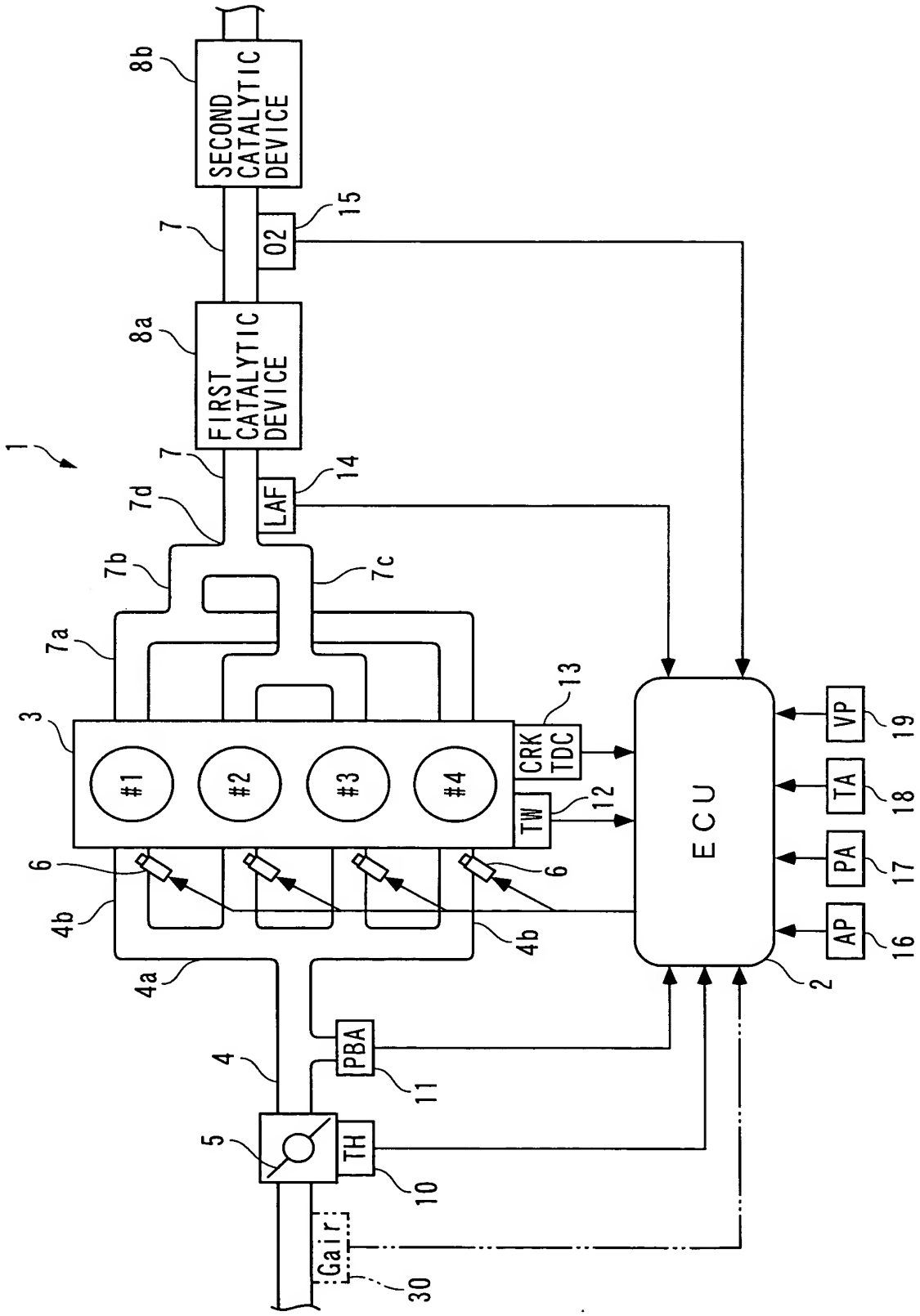
SECOND CATALYTIC DEVICE
FIRST CATALYTIC DEVICE
O2
LAF
#1
#2
#3
#4
CRK
TDC
TW
ECU
VP
TA
PA
AP
PBA
TH
Gair
1
2
3
4
4a
4b
5
6
7
7a
7b
7c
7d
8a
8b
10
11
12
13
14
15
16
17
18
19
30

FIG. 2

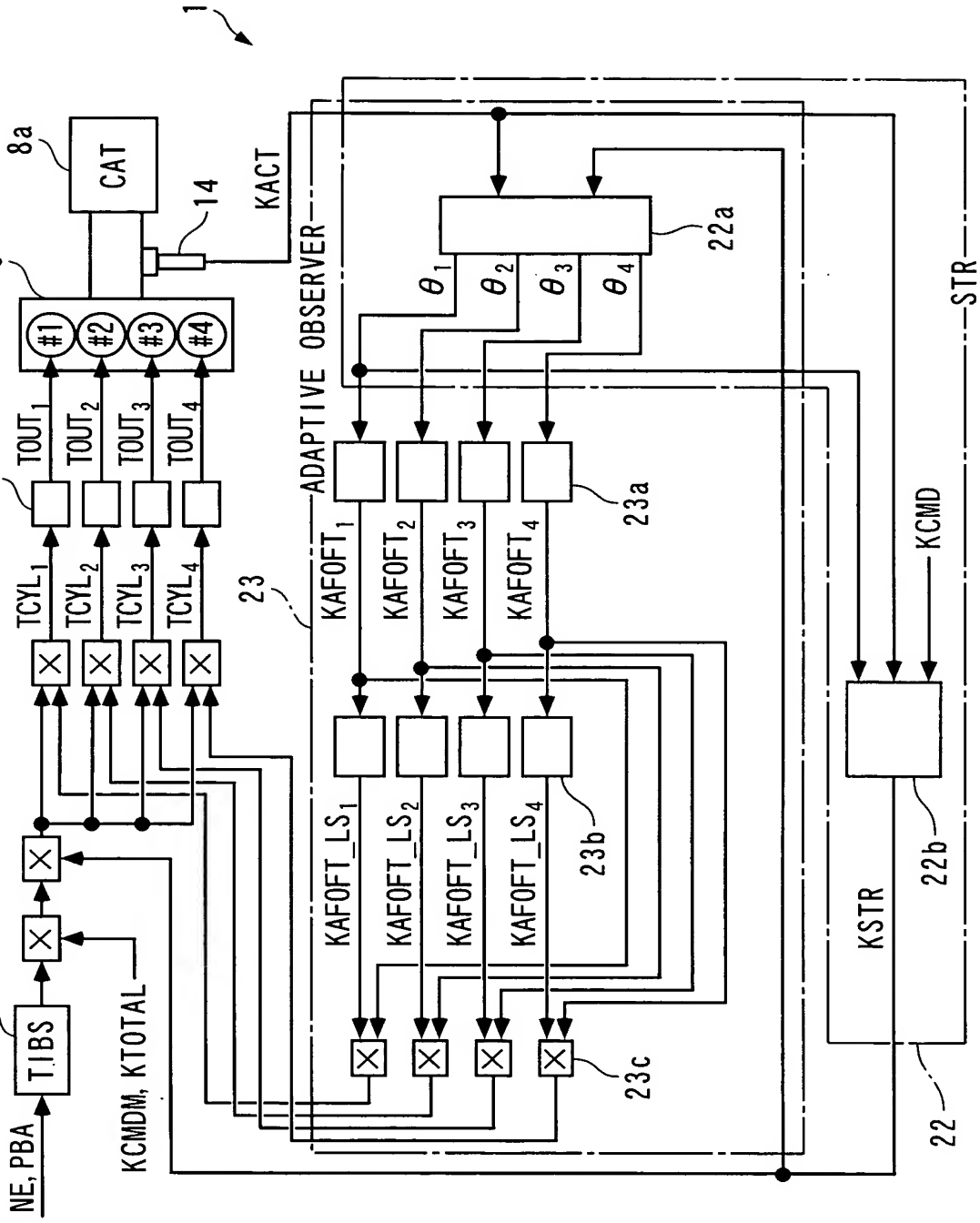
1
8a
CAT
14
KACT
3
#1
#2
#3
#4
TOUT1
TOUT2
TOUT3
TOUT4
24
TCYL1
TCYL2
TCYL3
TCYL4
ADAPTIVE OBSERVER
22a
θ1
θ2
θ3
θ4
STR
23
KAFOFT1
KAFOFT2
KAFOFT3
KAFOFT4
23a
KCMD
KAFOFT_LS1
KAFOFT_LS2
KAFOFT_LS3
KAFOFT_LS4
23b
KSTR
22b
23c
22
21
TIBS
NE, PBA
KCMDM, KTOTAL

FIG. 3

$$KACT_i(k) = b0_i(k) \cdot KSTR_i(k-3) + r1_i(k) \cdot KSTR_i(k-4) + r2_i(k) \cdot KSTR_i(k-5) + r3_i(k) \cdot KSTR_i(k-6) + s0_i(k) \cdot KACT_i(k-3) \quad \cdots\cdots (1)$$

$$KSTR_i(k) = \frac{1}{b0_i(k)} \cdot \left\{ KCMD_i(k) - r1_i(k) \cdot KSTR_i(k-1) - r2_i(k) \cdot KSTR_i(k-2) - r3_i(k) \cdot KSTR_i(k-3) - s0_i(k) \cdot KACT_i(k) \right\} \quad \cdots\cdots (2)$$

$$\theta_i(k) = \theta_i(k-1) + KP_i(k) \cdot ide_i(k) \quad \cdots\cdots (3)$$

$$\theta_i(k)^T = [b0_i(k),\ r1_i(k),\ r2_i(k),\ r3_i(k),\ s0_i(k)] \quad \cdots\cdots (4)$$

$$ide_i(k) = KACT_i(k) - KACT\_HAT_i(k) \quad \cdots\cdots (5)$$

$$KACT\_HAT_i(k) = \theta_i(k-1)^T \cdot \zeta_i(k) \quad \cdots\cdots (6)$$

$$\zeta_i(k)^T = [KSTR_i(k-3),\ KSTR_i(k-4),\ KSTR_i(k-5),\ KSTR_i(k-6),\ KACT_i(k-3)] \quad \cdots\cdots (7)$$

$$KP_i(k) = \frac{P_i(k) \cdot \zeta_i(k)}{1 + \zeta_i(k)^T \cdot P_i(k) \cdot \zeta_i(k)} \quad \cdots\cdots (8)$$

$$P_i(k+1) = \frac{1}{\lambda_1} \left(I - \frac{\lambda_2 \cdot P_i(k) \cdot \zeta_i(k) \cdot \zeta_i(k)^T}{\lambda_1 + \lambda_2 \cdot \zeta_i(k)^T \cdot P_i(k) \cdot \zeta_i(k)} \right) P_i(k) \quad \cdots\cdots (9)$$

I : UNIT PARAMETER
λ_1, λ_2 : WEIGHTING PARAMETER

FIG. 4

$$\theta\_ave(n) = \frac{1}{m+1}\{\theta buf(n) + \cdots + \theta buf(n-m)\} \quad \cdots\cdots (10)$$

$$\theta\_ave(n)^T = [b0\_ave(n),\ r1\_ave(n),\ r2\_ave(n),\ r3\_ave(n),\ s0\_ave(n)] \quad \cdots\cdots (11)$$

$$KSTR(n) = \frac{1}{b0\_ave(n)}\Big\{KCMD(n) - r1\_ave(n)KSTR(n-4) - r2\_ave(n)KSTR(n-8) - r3\_ave(n)KSTR(n-12) - s0\_ave(n)KACT(n)\Big\} \quad \cdots\cdots (12)$$

$$\theta_i(k) = \theta_i(k-1) + KP_i(k) \cdot ide_i(k) \quad \cdots\cdots (13)$$

$$\theta_i(k)^T = [b0_i(k),\ r1_i(k),\ r2_i(k),\ r3_i(k),\ s0_i(k)] \quad \cdots\cdots (14)$$

$$ide_i(k) = KACT_i(k) - KACT\_HAT_i(k) \quad \cdots\cdots (15)$$

$$KACT\_HAT_i(k) = \theta_i(k-1)^T \cdot \zeta_i(k) \quad \cdots\cdots (16)$$

$$\zeta_i(k)^T = [KSTR_i(k-3),\ KSTR_i(k-4),\ KSTR_i(k-5),\ KSTR_i(k-6),\ KACT_i(k-3)]$$
$$= [KSTR_i(n-12), KSTR_i(n-16), KSTR_i(n-20), KSTR_i(n-24), KACT_i(n-12)] \quad \cdots\cdots (17)$$

$$KP_i(k) = \frac{P_i(k) \cdot \zeta_i(k)}{1 + \zeta_i(k)^T \cdot P_i(k) \cdot \zeta_i(k)} \quad \cdots\cdots (18)$$

$$P_i(k+1) = \frac{1}{\lambda_1}\left(I - \frac{\lambda_2 \cdot P_i(k) \cdot \zeta_i(k) \cdot \zeta_i(k)^T}{\lambda_1 + \lambda_2 \cdot \zeta_i(k)^T \cdot P_i(k) \cdot \zeta_i(k)}\right) P_i(k) \quad \cdots\cdots (19)$$

I : UNIT PARAMETER
λ_1, λ_2 : WEIGHTING PARAMETER

FIG. 5

$$\theta_i(k) = \sigma f \cdot \theta_i(k-1) + KP_i(k) \cdot ide_i(k) \quad \cdots\cdots (20)$$

$$\theta_i(k)^T = [b0_i(k), r1_i(k), r2_i(k), r3_i(k), s0_i(k)] \quad \cdots\cdots (21)$$

$$ide_i(k) = KACT_i(k) - KACT\_HAT_i(k) \quad \cdots\cdots (22)$$

$$KACT\_HAT_i(k) = \theta_i(k-1)^T \cdot \zeta_i(k) \quad \cdots\cdots (23)$$

$$\zeta_i(k)^T = [KSTR_i(k-3), KSTR_i(k-4), KSTR_i(k-5), KSTR_i(k-6), KACT_i(k-3)]$$
$$= [KSTR_i(n-12), KSTR_i(n-16), KSTR_i(n-20), KSTR_i(n-24), KACT_i(n-12)]$$
$$\cdots\cdots (24)$$

$$KP_i(k) = \frac{\boldsymbol{P}f \cdot \zeta_i(k)}{1 + \zeta_i(k)^T \cdot \boldsymbol{P}f \cdot \zeta_i(k)} \quad \cdots\cdots (25)$$

$\boldsymbol{P}f$: IDENTIFICATION GAIN(VECTOR HAVING 1 ROW AND 5 COLUMNS)

$$\sigma f = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & a & 0 & 0 & 0 \\ 0 & 0 & a & 0 & 0 \\ 0 & 0 & 0 & a & 0 \\ 0 & 0 & 0 & 0 & a \end{bmatrix} \quad (0 < a < 1) \quad \cdots\cdots (26)$$

σf : FORGETTING VECTOR

FIG. 6

$$KACT' = bO_i(k) \cdot KSTR' + r1_i(k) \cdot KSTR' + r2_i(k) \cdot KSTR' + r3_i(k) \cdot KSTR' + sO_i(k) \cdot KACT' \quad \cdots\cdots (27)$$

$$[1 - sO_i(k)]KACT' = [bO_i(k) + r1_i(k) + r2_i(k) + r3_i(k)]KSTR' \quad \cdots\cdots (28)$$

$$KACT' = \frac{bO_i(k) + r1_i(k) + r2_i(k) + r3_i(k)}{1 - sO_i(k)} \cdot KSTR' \quad \cdots\cdots (29)$$

$$AFOFT_i(k) = \frac{bO_i(k) + r1_i(k) + r2_i(k) + r3_i(k)}{1 - sO_i(k)} \quad \cdots\cdots (30)$$

$$AFOFTAVE(n) = \frac{1}{mc} \cdot \sum_{i=1}^{mc} AFOFT_i(n) \quad \cdots\cdots (31)$$

mc : NUMBER OF CYLINDERS

$$KAFOFT_i(n) = -GI \cdot \sum_{j=0}^{n} e(j) - FI \cdot AFOFT_i(n) - HI \cdot [AFOFT_i(n) - AFOFT_i(n-1)] \quad \cdots\cdots (32)$$

FI, GI, HI : FEEDBACK GAINS

$$e(n) = AFOFT_i(n) - AFOFTAVE(n) \quad \cdots\cdots (33)$$

FIG. 7A

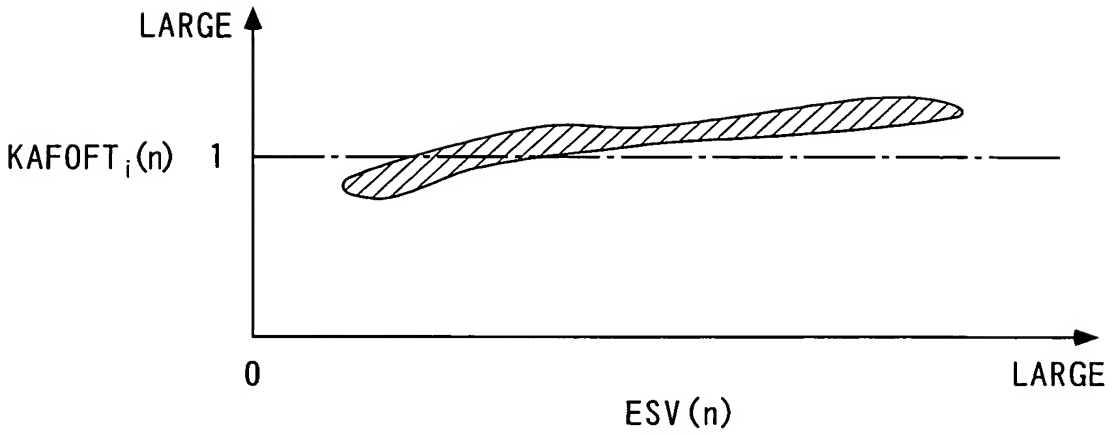
LARGE
KAFOFT$_i$(n)
1
0
LARGE
ESV(n)

FIG. 7B

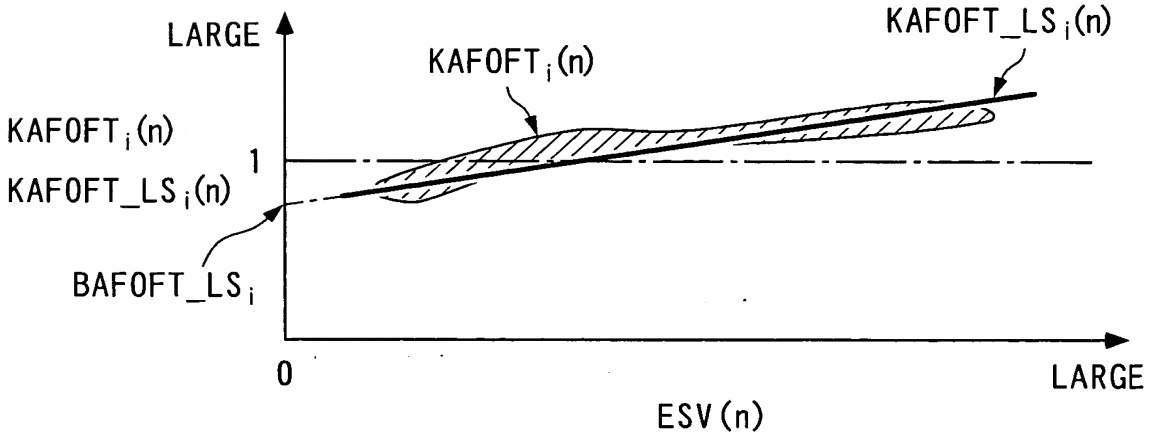
LARGE
KAFOFT_LS$_i$(n)
KAFOFT$_i$(n)
KAFOFT$_i$(n)
1
KAFOFT_LS$_i$(n)
BAFOFT_LS$_i$
0
LARGE
ESV(n)

FIG. 8

$$ESV(n)=\frac{NE(n)}{1500}\cdot PBA(n)\cdot SVPRA \quad \cdots\cdots (34)$$

$$KAFOFT\_LS_i(n)=AAFOFT\_LS_i\cdot ESV(n)+BAFOFT\_LS_i \quad \cdots\cdots (35)$$

$$\theta AFOFT\_LS_i(n)=\theta AFOFT\_LS_i(n-1)+KQ_i(n)\cdot Eaf_i(n) \quad \cdots\cdots (36)$$

$$\theta AFOFT\_LS_i(n)^T=[AAFOFT\_LS_i(n),\ BAFOFT\_LS_i(n)] \quad \cdots\cdots (37)$$

$$Eaf_i(n)=KAFOFT_i(n)\cdot KAFOFT\_LS_i(n)-\theta AFOFT\_LS_i(n-1)^T\cdot Z(n) \quad \cdots\cdots (38)$$

$$KAFOFT\_LS_i(n)=\theta AFOFT\_LS_i(n-1)^T\cdot Z(n) \quad \cdots\cdots (39)$$

$$Z(n)^T=[ESV(n),\ 1] \quad \cdots\cdots (40)$$

$$KQ_i(n)=\frac{Q_i(n)\cdot Z(n)}{1+Z_i(n)\cdot Q_i(n)\cdot Z(n)} \quad \cdots\cdots (41)$$

$$Q_i(n+1)=\frac{1}{\lambda_1'}\cdot\left(I-\frac{\lambda_2'\cdot Q_i(n)\cdot Z(n)^T\cdot Z(n)}{\lambda_1'+\lambda_2'\cdot Z(n)^T\cdot Q_i(n)\cdot Z(n)}\right)\cdot Q_i(n) \quad \cdots\cdots (42)$$

I : UNIT PARAMETER
λ_1', λ_2' : WEIGHTING PARAMETER

$$KAFOFT\_LS_i(n)=\theta AFOFT\_LS_i(n-1)^T\cdot Z(n)$$
$$=AAFOFT\_LS_i(n-1)\cdot ESV(n)+BAFOFT\_LS_i(n-1) \quad \cdots\cdots (43)$$

FIG. 9

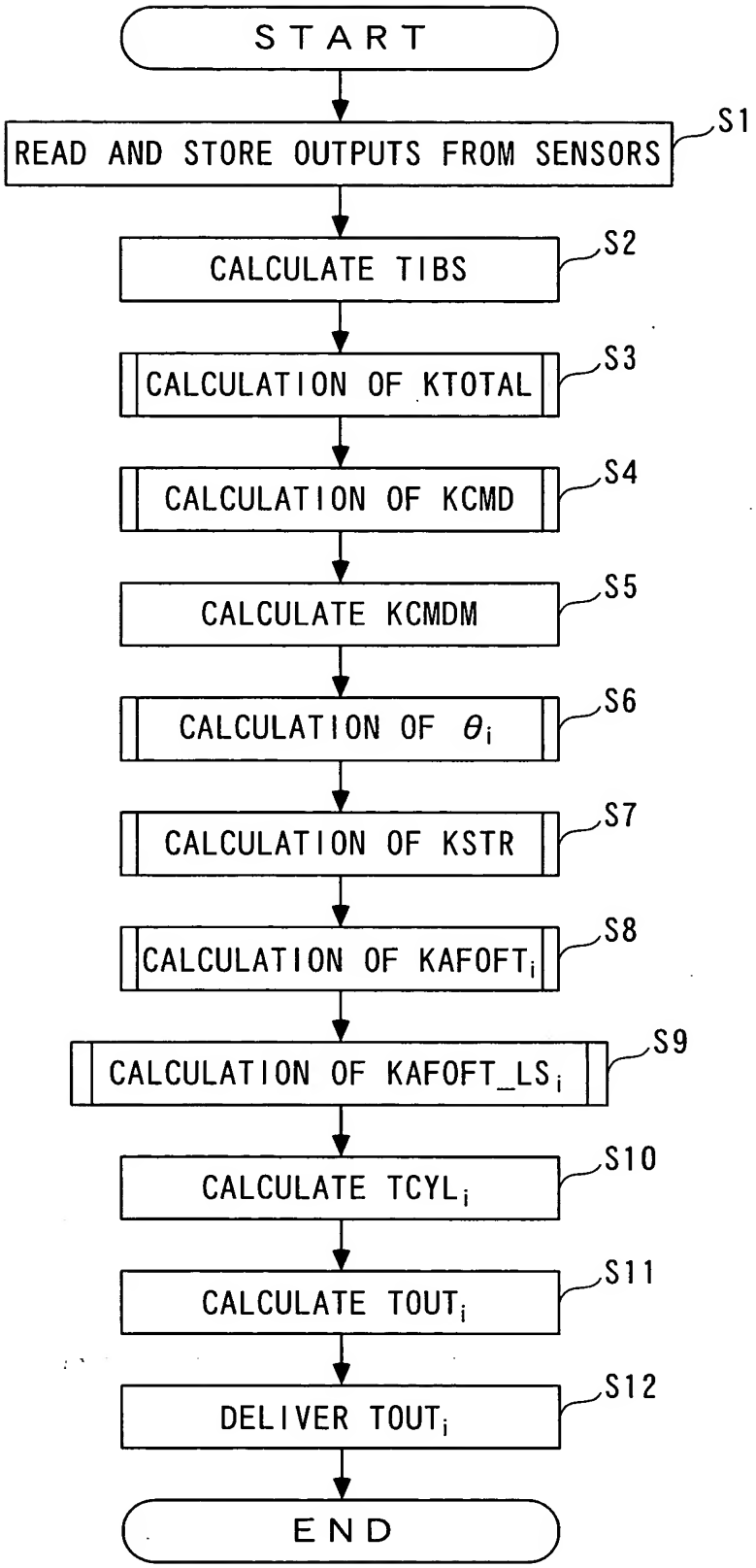
START
READ AND STORE OUTPUTS FROM SENSORS
S1
CALCULATE TIBS
S2
CALCULATION OF KTOTAL
S3
CALCULATION OF KCMD
S4
CALCULATE KCMDM
S5
CALCULATION OF θi
S6
CALCULATION OF KSTR
S7
CALCULATION OF KAFOFTi
S8
CALCULATION OF KAFOFT_LSi
S9
CALCULATE TCYLi
S10
CALCULATE TOUTi
S11
DELIVER TOUTi
S12
END

FIG. 10

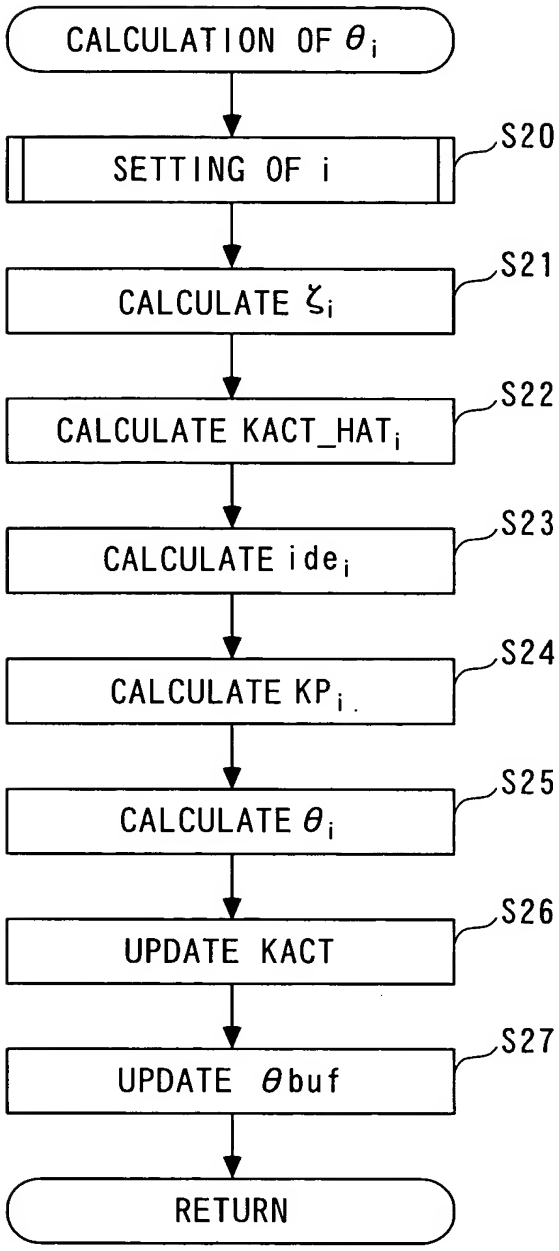
CALCULATION OF θ_i
SETTING OF i
S20
CALCULATE ζ_i
S21
CALCULATE KACT_HAT$_i$
S22
CALCULATE ide$_i$
S23
CALCULATE KP$_i$
S24
CALCULATE θ_i
S25
UPDATE KACT
S26
UPDATE θbuf
S27
RETURN

FIG. 11

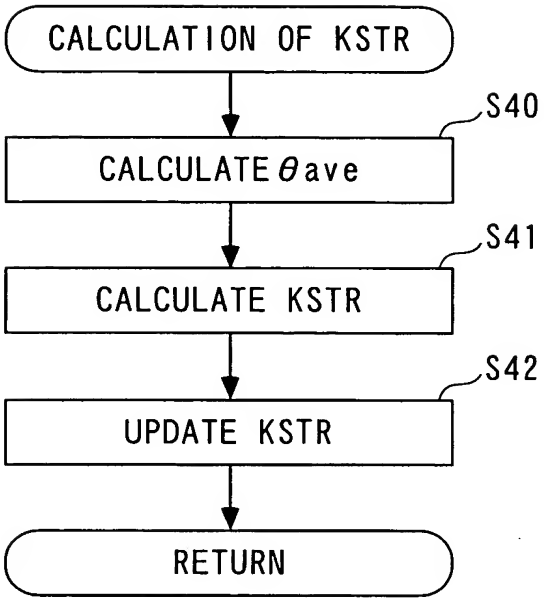
CALCULATION OF KSTR
S40
CALCULATE θave
S41
CALCULATE KSTR
S42
UPDATE KSTR
RETURN

FIG. 12

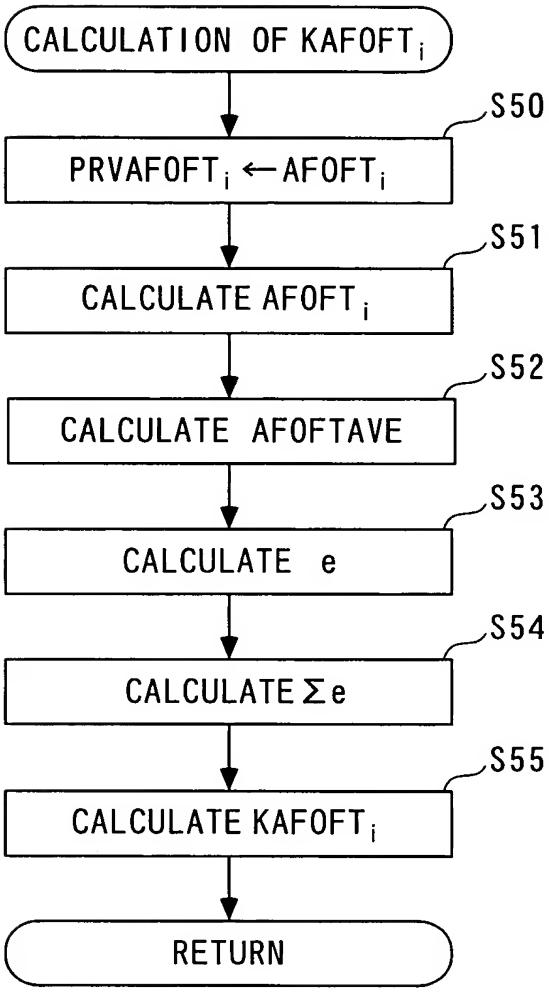
CALCULATION OF KAFOFT$_i$
S50
PRVAFOFT$_i$ ← AFOFT$_i$
S51
CALCULATE AFOFT$_i$
S52
CALCULATE AFOFTAVE
S53
CALCULATE e
S54
CALCULATE Σe
S55
CALCULATE KAFOFT$_i$
RETURN

FIG. 13

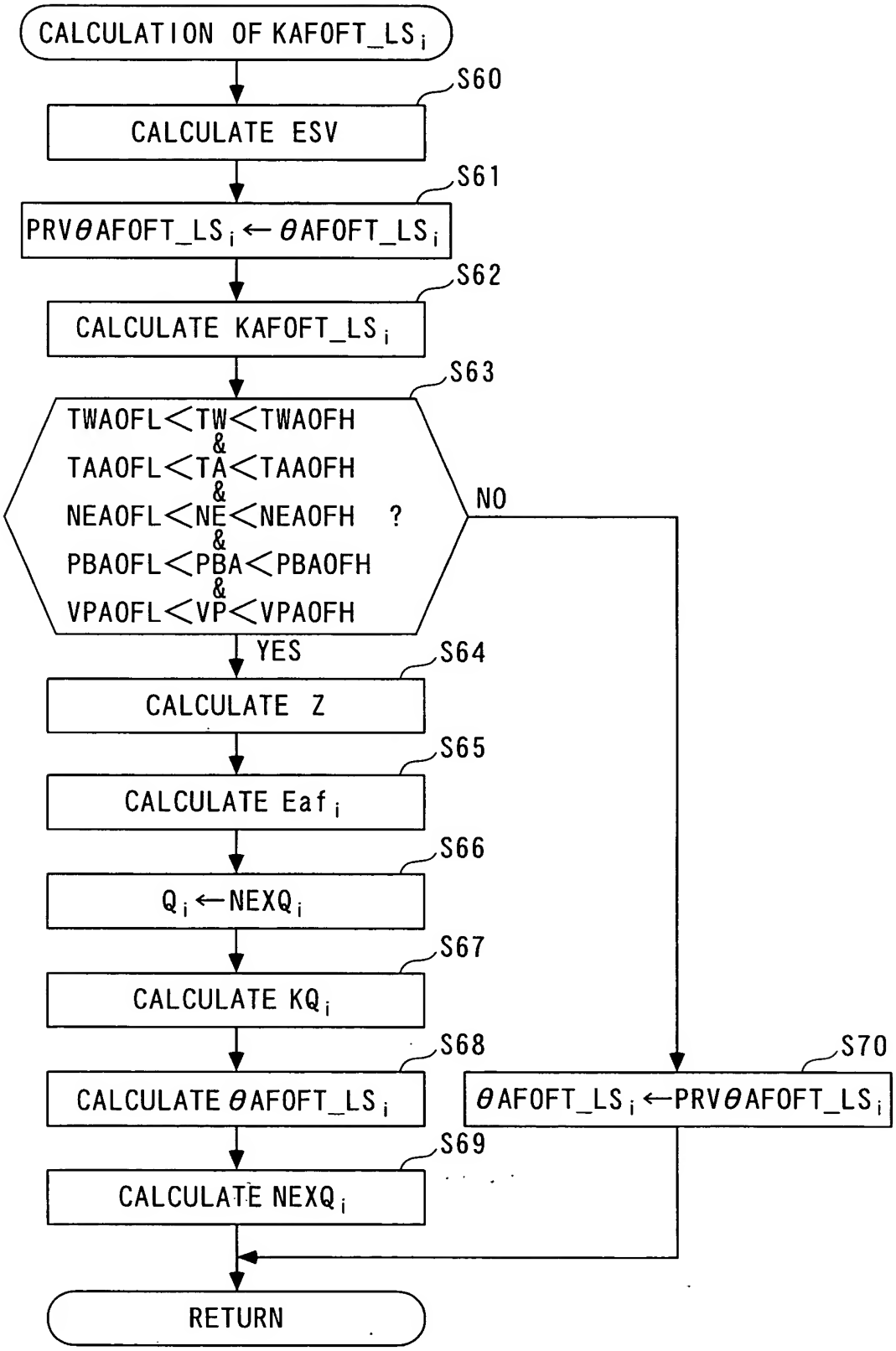
CALCULATION OF KAFOFT_LS$_i$
S60
CALCULATE ESV
S61
PRVθAFOFT_LS$_i$ ← θAFOFT_LS$_i$
S62
CALCULATE KAFOFT_LS$_i$
S63
TWAOFL＜TW＜TWAOFH
&
TAAOFL＜TA＜TAAOFH
&
NEAOFL＜NE＜NEAOFH ?
&
PBAOFL＜PBA＜PBAOFH
&
VPAOFL＜VP＜VPAOFH
NO
YES
S64
CALCULATE Z
S65
CALCULATE Eaf$_i$
S66
Q$_i$ ← NEXQ$_i$
S67
CALCULATE KQ$_i$
S68
CALCULATE θAFOFT_LS$_i$
S69
CALCULATE NEXQ$_i$
S70
θAFOFT_LS$_i$ ← PRVθAFOFT_LS$_i$
RETURN

FIG. 14

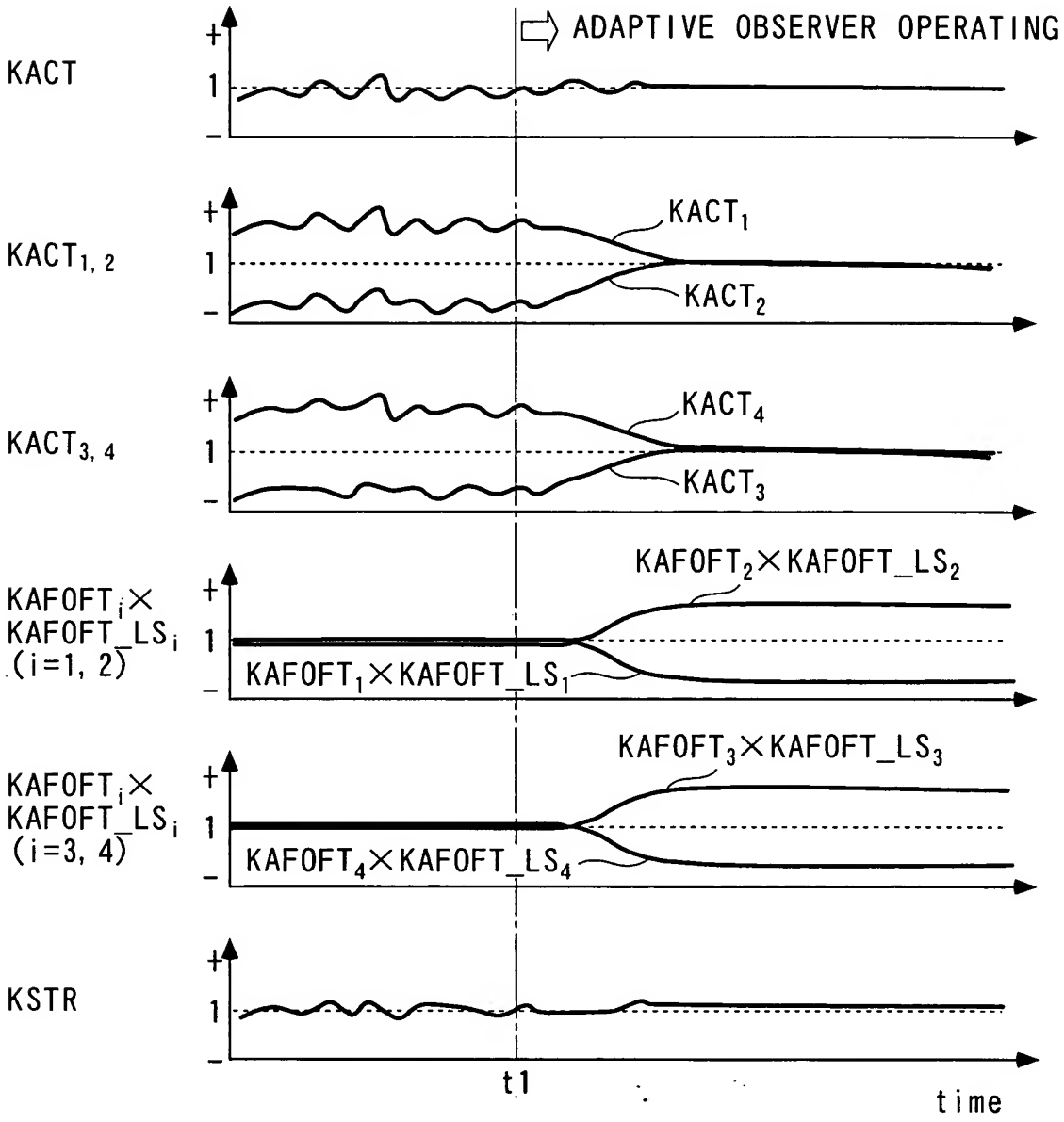
ADAPTIVE OBSERVER OPERATING
KACT
KACT1, 2
KACT1
KACT2
KACT3, 4
KACT4
KAFOFTi×KAFOFT_LSi (i=1, 2)
KAFOFT2×KAFOFT_LS2
KAFOFT1×KAFOFT_LS1
KAFOFTi×KAFOFT_LSi (i=3, 4)
KAFOFT3×KAFOFT_LS3
KAFOFT4×KAFOFT_LS4
KSTR
+
1
−
t1
time

FIG. 15

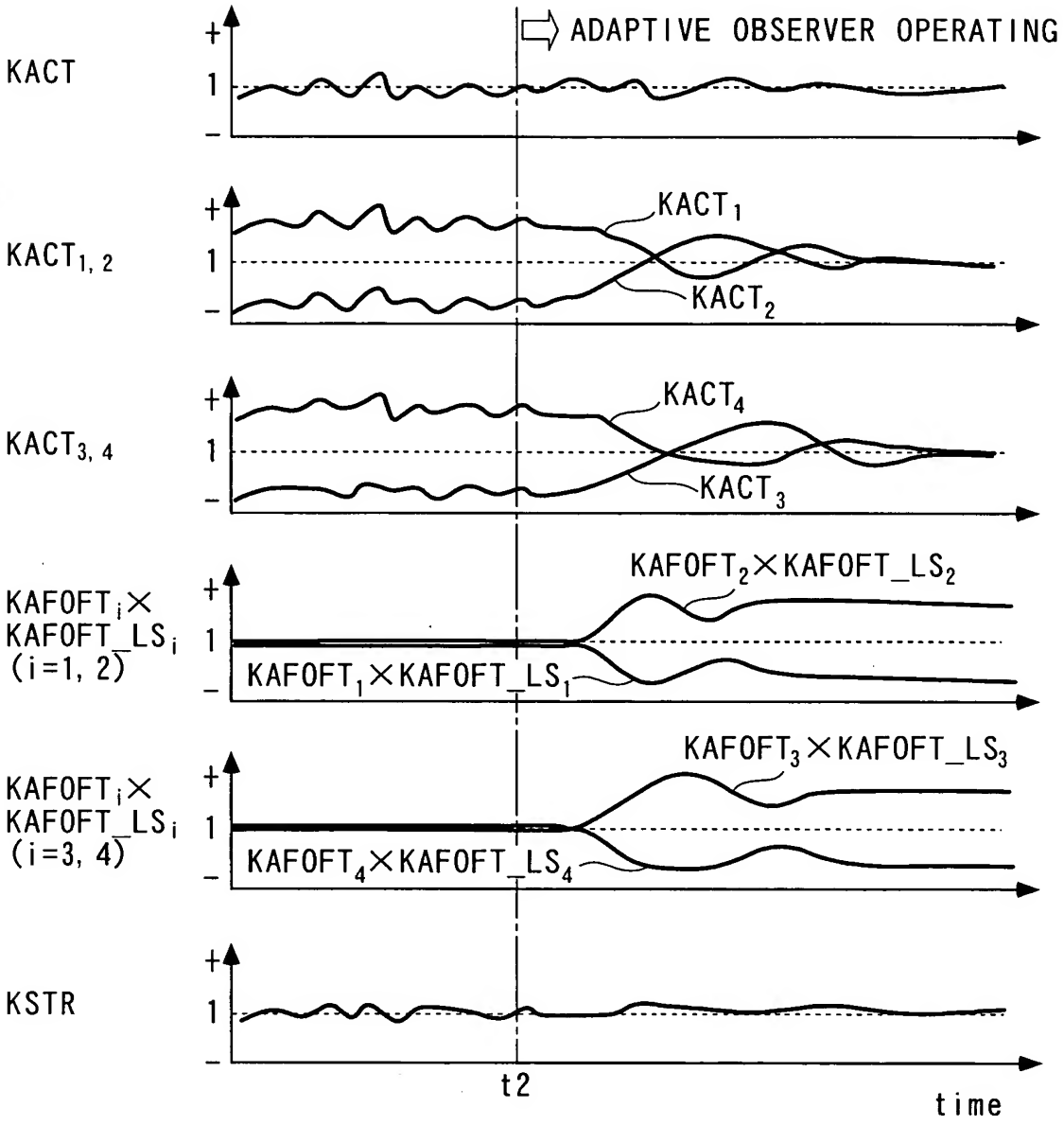
KACT
+
1
−
⇨ ADAPTIVE OBSERVER OPERATING
KACT1, 2
KACT1
KACT2
KACT3, 4
KACT4
KACT3
KAFOFTi×
KAFOFT_LSi
(i=1, 2)
KAFOFT2×KAFOFT_LS2
KAFOFT1×KAFOFT_LS1
KAFOFTi×
KAFOFT_LSi
(i=3, 4)
KAFOFT3×KAFOFT_LS3
KAFOFT4×KAFOFT_LS4
KSTR
t2
time

FIG. 16

IP-D CONTROL ALGORITHM

$$KAFOFT_i(n) = -GD \cdot \sum_{j=0}^{n} e(j) - FD \cdot e(n) - HD \cdot [AFOFT_i(n) - AFOFT_i(n-1)] \quad \cdots\cdots (45)$$

$$e(n) = AFOFT_i(n) - AFOFTAVE(n) \quad \cdots\cdots (46)$$

FD, GD, HD : FEEDBACK GAINS

RESPONSE-SPECIFIED CONTROL ALGORITHM

$$KAFOFT_i(n) = -FS \cdot \sigma(n) - GS \cdot \sum_{j=0}^{n} \sigma(j) - HS \cdot e(n) \quad \cdots\cdots (47)$$

$$e(n) = AFOFT_i(n) - AFOFTAVE(n) \quad \cdots\cdots (48)$$

$$\sigma(n) = e(n) + S \cdot e(n-1) \quad \cdots\cdots (49)$$

$\sigma(n)$: SWITCHING FUNCTION
FS, GS, HS : FEEDBACK GAINS
S : SWITCHING FUNCTION-SETTING PARAMETER